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Selecting the most appropriate tractor using Analytic Hierarchy Process – An Iranian case study

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A B S T R A C T

With regard to the importance of selecting an appropriate tractor in rural areas which is one of the main tasks for most farmers, the aim of this study is to select the best tractor in Ghaemshahr and Ahvaz cities of Iran. The methodology of the paper is descriptive-analytic and data were collected through library and field works (interviews and questionnaires). The statistic population of this study was 25 tractors in Ghaemshahr and Ahvaz, in that 15 tractors were chosen randomly, and the data were analyzed using AHP (analytic hierarchy process). The results showed that the maximum effect regarding the selection of tractor belonged to the maintenance with 49.4% and the minimum went to ergonomic effect with 7% in Ahvaz and the maximum effect was related to price with 29.6% and the minimum went to ergonomic effect with 6.8%. ITM285 and Romania 650 with 83% were the best tractors in Ahvaz and John Deere 6150 with 83% was the best tractor in Ghaemshahr city. Incompatibility ratio for all the comparisons was zero, so the criteria are completely compatible with the aims and options.

1. Introduction

Selection is a broad comparison of suppliers using a common set of criteria and measures. However, the level of detail used for examining potential suppliers may vary depending on a firm's needs. Studies conducted on Danish farms show vast differences in machine costs, ranging from 3000 to 7000 DKK ha1 [21]. This clearly emphasises the importance of developing methods for choosing the optimal machinery.

The Analytic Hierarchy Process (AHP) is a method of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales [32,33]. It has been one of the most widely used multiple criteria decision-making tools [40]. It is used by decision makers and researchers, because it is a simple and powerful tool [15]. In fact, the hierarchical structure of AHP methodology is able to measure and synthesize a variety of factors of a complex decision making process in a hierarchical manner, making it simple to combine the parts in a whole. A bibliometric research [41] found that the number of publications related to MCDM – Multi-Criteria Decision Making/MAUT–Multi-Attribute Utility Theory – increased 4.2 times from 1992 to 2006. This phenomenon can be mostly attributed to a relevant growth of the publications focused on AHP and EMO – Evolutionary Multi-Objective Optimization.

Putting together an ideal machinery system is not easy. On the other hand, the limitation of resources in agriculture shows the importance of appropriate technology selection

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to optimize the limited and expensive resources in agriculture. Conquering technical and climate limitations as well as temporal constraints, mechanical technologies provides the possibility of increasing the acreage and the production of the agricultural sector. In fact, mechanical technologies make possible the application of research findings in different agricultural branches. As a result, agricultural mechanization has become an undeniable necessity for increasing productivity use in other inputs [13].

AHP has been applied in different fields such as planning, alternative selection, resource allocation, and optimization [24]. The uniqueness of AHP is its flexibility to be integrated with different techniques like linear programming, QFD, and fuzzy logic [12]. This enables the user to extract benefits from all the combined methods, and hence, achieve the desired goal in a better way [40].

In this study it is focused on the agricultural machinery selection which is the important part of the machinery management decision. Among the agricultural machines, tractors are handled. Tractor is one of the most important tools on acreage and plays an important role in agricultural production. The purchase of a tractor and associated equipment need substantial investment. The result of improper tractor selection can be costly. For example when a relatively small tractor is chosen for a large land, it's faced with long hours in the field, excessive delays and premature replacement whereas a relatively big tractor can result in excessive operating and overhead costs [36].

Many researchers have used AHP for different purposes, for example, Ahadi and Ghazanfar-Rad [1] used it for selecting the best rolling stock provider, Kahraman et al. [22] used a fuzzy AHP for choosing the best provider in Turkish White factory; decision makers could determine the priority and preference for selecting a provider using fuzzy logic variables. The triangle fuzzy numbers were used in the method and the analysis of development method was used for analyzing paired comparisons. Kilincci and Onal [23] used a fuzzy AHP method for selecting the provider. This choice was based on the customers' satisfaction. Russo and Camanho [29], in their study as "Criteria in AHP: a systematic review of literature", tried to develop a systematic review of literature on the real cases that applied AHP to evaluate how the criteria are being defined and measured. In the 33 cases selected, they mainly used literature to build the criteria and AHP or Fuzzy AHP to calculate their weight, while other techniques were used to evaluate alternatives. Tam and Tummala [38] have used AHP in vendor selection of a telecommunication system, which is a complex, multi-person and multi-criteria decision problem. They have found AHP to be very useful in involving several decision makers with different conflicting objectives to arrive at a consensus decision. The decision process as a result is systematic and reduces time to select the vendor. Byun [10] used an extended version of AHP in the selection of a car; he focused on two issues: one issue combines the pairwise comparison with a spreadsheet method using a five-point rating scale and the other issue applies group weights to consistency ratio (CR). AlKhalil [2] used AHP to select the most appropriate project delivery method as key project success factor. The model developed using AHP was found to be easy to use and allows the owner to consider all decision-relevant factors. Choughle and Ravi [14] have proposed variant process planning of castings using AHP-based nearest neighbour algorithm for case retrieval. Ayag [7] has proposed a hybrid approach to machine-tool selection through AHP and simulation.

Mehta et al. [25] developed a Decision Support System (DSS) to select a tractor and its matching equipment for different soils and operating conditions. Zhou [44] proposed a new comprehensive assessment method, which combines neural networks and support vector machine based on Particle Swarm Optimization (PSO). Grisso et al. [18] used tractor test data for selecting farm tractors. García-Alcaraz et al. [17] proposed hybrid and multi-attribute approach to assess a set of agricultural tractors based on Analytic Hierarch Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. Bol and Mohammed [8] developed a mathematical model for farm machinery selection. Osman [27] developed a model for optimization of farm machinery management by linear programming.

Lin and Yang [24] developed a model for the selection of the most suitable machine from a range of machines available for the manufacture of particular part types. In their study, there were four main criteria: machine procedures, lead time, labor cost, and operation shift; and three alternatives: conventional machines, NC machines, and flexible manufacturing cells. Tabucanon et al. [37] developed a decision support framework designed to aid decision-makers in selecting the most appropriate machines for flexible manufacturing systems (FMS). The framework consists of two main stages. The first stage, called as the pre-screening stage, narrows down all possible configurations using AHP. The second stage uses a goal programming (GP) model. Yurdakul [43] presents a model that links machine alternatives to manufacturing strategy for machine tool selection. In his study, the evaluation of investment in machine tools can model and quantify strategic considerations by using the AHP method. On the other hand, Cheng et al. [11] claim that although AHP is an effective tool for management decision-making, it can be defective if used improperly. Wang et al. [42] suggest a fuzzy multiple-attribute decision-making model to assist the decision-maker in dealing with the machine selection problem for FMS. A linear 0–1 integer programming model for machine tool assignment and operation allocation in FMS is proposed by Atmani and Lashkari [6]. Their model determines the optimal machine-tool combinations and assigns the operations of the part types to the machines (minimizing total costs of processing, material handling, and machine setups). A machine tool selection problem similar to ours is addressed by Arslan et al. [5] and a multi-criteria weighted average approach is proposed.

Uma Devi et al. [39] in their study as "Vendor Selection Using AHP" propos an analytic hierarchy process model for selecting the best vendor among the alternatives. The choice of the right vendor is a crucial decision with wide ranging implications in a supply chain. The proposed model can help the firm in selecting the efficient vendor. AHP is multicriteria decision making tool that takes into account both qualitative and quantitative criterias.

The general points and considerations for an appropriate selection in the view of Almasi et al. [3] are as follows:

considering the international brand on machinery, paying attention to the trade name, considering different models of a brand or mark, paying attention to repair and after sales services, machine design, machine application convenience, easy options, work security, ergonomic issues. Different agricultural operations need different appropriate tractors to optimize the operation. On the other hand, farmers cannot buy different models and, therefore, choosing the appropriate tractor that can accomplish most of farms' work is a necessity.

With regard to the importance of selecting an appropriate tractor in rural areas which is one of the main tasks for most farms, the goal of the present study is to recognize the most appropriate tractor in Ghaemshahr and Ahvaz Cities of Iran. In this study, to determine the proper indices, apart from using the indexes used in the previous studies, farmers' viewpoints were also considered and at the end the following indexes and criteria were used in Table 1.

2. Materials and methods

2.1. The case study

Ghaemshar is a city located in 36 degrees and 21 minutes to 36 degrees and 38 minutes north latitude, and 52 degrees and 43 minutes to 53 degrees and 3 minutes east from prime meridian, with medium height of 51.2 m from the sea, and has approximately 740 square kilometers area, that covers 1.93% of the province. The total annual rainfall of the area is roughly 724.9 mm. Ghaemshar is close to Savadkouh from south, to Jouybar from north, to Sari from east and to Babol from west. Ghaemshar has 2 towns, 2 sectors, 6 rural districts, 156 villages with residents and 3 villages without any resident. Based on the census statistical center of Iran in 2006, its population is 320,741.

Ahvaz is located in 31 degrees and 20 minutes north latitude, and 48 degrees and 40 minutes east, in the plains of Khuzestan and with 18 m height from the sea. Ahvaz has 20,000-hectare area and its population in 2006 census was 1,059,461, which made it the seventh crowded city of Iran [4].

2.2. Analytical hierarchy process

This research follows from selecting the appropriate tractor background information collections, questionnaire survey, data synthesis and structuring of hierarchy, results from AHP application and finally sensitivity analysis. These steps are described in following sections. The obtained information is processed through Analytical hierarchy process (AHP) using software called Expert Choice [20]. The work flow, as shown in Fig. 1, is followed in the study and explained in following sub sections.

The methodology of the present study is descriptive-analytic and it is an applied kind of research. Since the purpose of the study was to prioritize tractors, the questionnaire findings were analyzed and evaluated using AHP. The basis of this method was to make a decision making hierarchical tree. Fig. 2 shows the overall structure of AHP tree.

Level one includes the main purpose, prioritizing the tractors.

Level two includes the evaluated indexes, criteria and parameters in tractors as presented in Table 1.

Final level includes tractors that are presented in Table 2. In this study, it has been attempted to prioritize among the mentioned factors.

2.3. Essentials of AHP

AHP is a decision-aid that can provide the decision maker (DM) with relevant information to assist the DM in choosing the appropriate alternative [9] or to rank a set of alternatives. It is one of the easily applicable MCA tools which generally contains the stages [28] of choosing decision options and evaluation criteria, obtain performance measures for the evaluation matrix, transform into commensurate units, weight the criteria, rank or score the options, perform sensitivity analysis and finally make a decision. A decision maker specifies the desired outcome as a goal. The goal provides the target that indicates preferred or expected results. Solutions can be uncovered in many ways including managing by talking about, drawing ideas from alliance partners, environmental scanning, reading and conferencing, commissioning reports, innovation attempts and other ways to acquire knowledge. Technical, social, environmental, economic and political aspects need to be hierarchically structured in attributes and goals since the conception of project [16–26]. All criteria along with associated sub criteria and alternatives must be reviewed simultaneously with respect to major stakeholders. Finally, different criteria and stakeholder's views need to be resolved within a framework of understanding and mutual compromise [19]. In this regard, AHP is widely used for decision making based on several groups of decision makers [35] involved where groups conflicts among different interest: stakeholders, owners, managers, ecologists and public may have similar or specific goals.

The AHP is based on the axiomatic foundation [31–34] that provides the theoretical base and on which the method was founded. The axiomatic foundations are as follows:

Table 1 – Indexes and criteria for tractor selection.

Operational definition of criteria	Criteria
Average costs spent by farmers for buying the tractor	Average price
The costs for repair and maintenance in case of the existence of repair tools	Repair and maintenance average
The required power for farmers' works	Production power average
Convenience rate with tractor for agricultural works	Ergonomic average
Studying the importance of the farmers' choice of a model in comparison with other models	Model average

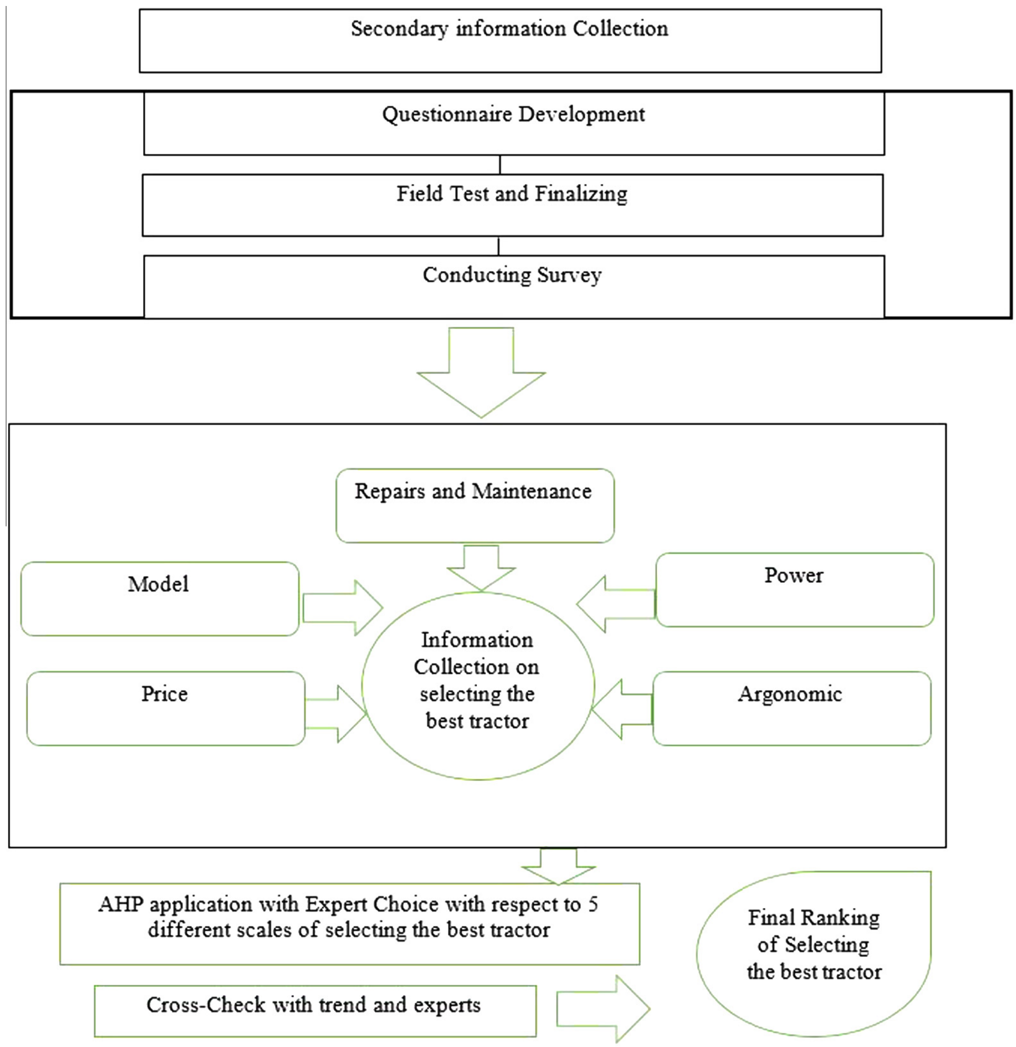

Fig. 1 – Methodological steps in application of AHP in the study.

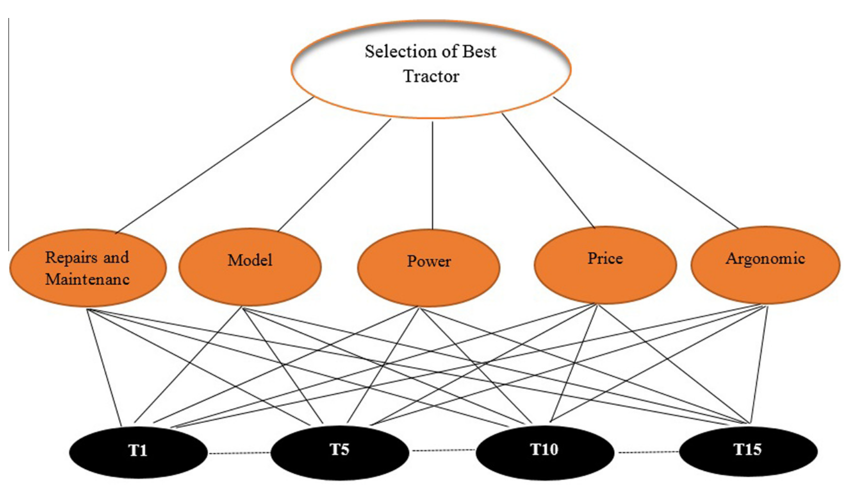

Fig. 2 – Overall structure of AHP tree (AHP Model).

Table 2 – Values and options.

Models of tractors	Alternatives
ITM 285	T1
ITM 285-4WD	T2
ITM 299	T3
ITM 299-4WD	T4
ITM 399	T5
ITM 399-4WD	T6
NEW Holland TS125	T7
NEW Holland TM155	T8
NEW Holland T7030	T9
T171 Valtra	T10
DTM 604	T11
Romania 650	T12
Europars 404	T13
John Deere 6150	T14
OTM 950	T15

1. The reciprocal property that was basic in making paired comparisons. If PC (EA, EB) was a paired comparison of elements A and B with respect to their parent, element C, representing how many times more the element A possesses a property than does element B, then PC (EB, EA) = 1/PC (EA, EB). Suppose A is 5 times larger than B, then B is one fifth as large as A.
2. The second, or homogeneity axiom, states that the elements being compared should not differ by too much, otherwise there will tend to be larger errors in judgment. Homogeneity that is characteristic of people's ability for making paired comparisons among things that are not too dissimilar with respect to a common property and, hence, need for arranging them within an order preserving hierarchy.
3. Dependence of a lower level on the adjacent higher level. The third, synthesis axiom states that judgments about the priorities of the elements in a hierarchy do not depend on lower level elements. This axiom is required for the principle of hierarchic composition to apply and apparently means that the importance of higher level objectives should not depend on the priorities or weights of any lower level factors.
4. The idea that an outcome can only reflect expectations when the latter are well represented in the hierarchy. Individuals who have reasons for their beliefs should make sure that their ideas are adequately represented for the outcome to match these expectations. It is important because the generality of AHP makes it possible to apply AHP in a variety of ways and adherence to this axiom prevents applying AHP in inappropriate ways.

The work on the AHP involves the estimation of priority weights of a set of criteria or alternatives from a square matrix of pairwise comparison $A = [a_{ij}]$, which is positive and if the paired comparison judgment is perfectly consistent it is reciprocal, i.e., $a_{ij} = 1/a_{ji}$ for all $ij = 1, 2, 3 \ldots n$.

The final normalized weight of its i-th factor, w_i, is given by Eq. (1).

$$w_i = \frac{a_{ij}}{(\sum_{k=1}^{n} ak_j)} \quad \forall i = 1, 2, \ldots, n. \tag{1}$$

In the real life judgment an error on the judgment is unavoidable. The suggested Eigen value method computes was the principal right Eigen value of the matrix A or w satisfies the following system of n linear equations:

$A\ w = \lambda$ max w, where λ max is the maximum Eigen value of A. This was calculated by using Eq. (2).

$$w_i = \frac{\sum_{j=1}^{n} a_{ij} w_j}{\lambda \text{ max}} \quad \forall i = 1, 2, \ldots, n. \tag{2}$$

The natural measure of inconsistency or deviation from consistency, called consistency index (CI) is defined by Eq. (3).

$$CI = \frac{\lambda \text{ max} - n}{n - 1} \tag{3}$$

The consistency index of a randomly generated reciprocal matrix from scale 1 to 9, with reciprocals forced, for each size of matrix called random index (RI) is presented in Table 3.

Consistency ratio (CR) = CI/RI, where RI is function of matrix size and CR < 0.01 is as an acceptable limit, otherwise need to be revised and adjusted accordingly.

Another task in the hierarchy is the synthesis of the judgments throughout the hierarchy in order to compute the overall priorities of the alternatives with respect to the goal. The weights are created by summing the priority of each element according to a given criterion by the weights of that criterion.

2.3.1. *Comparisons of alternatives in AHP*

One of the most widely applied pairwise comparison techniques is the Analytic Hierarchy Process [30]. These approaches involve comparing criteria and alternatives in every unique pair comparison. Based on the measured value (both objective as well as subjective) of respective criteria, in AHP application, DM makes pairwise comparison with regard to attaining the objective of research. The comparison can be made to attain criteria weights and decision option performance scores. Various scaling systems can be used. AHP decision makers are asked to express preference for one criterion/option over another in each pair on a nine-point scale as shown in Table 4.

3. Results and discussions

3.1. *Comparison of criteria with regard to purpose*

In the first stage, the criteria were paired compared in terms of purpose of the study (prioritizing the appropriate tractor). According to Fig. 3, which shows paired comparison of criteria in terms of purpose of the study in Ghaemshahr, the average price criterion with 0.296, and ergonomic criterion with 0.068 had the maximum and minimum priority, respectively, and according to Fig. 4, which shows paired comparison of criteria with regard to the purpose of study in Ahvaz, average criterion of repair and maintenance with 0.494 and ergonomic criterion with 0.070 proportions had the maximum and minimum preferences, respectively.

3.2. *Paired comparison of options*

In the second stage, options were paired compared with criteria. Fig. 5 shows weights of options with regard to the

Table 3 – Incompatibility index of random matrixes. Source: [20].

Matrix order	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.45

Table 4 – Scale of pair-wise comparison. Source: [19].

Numerical amount	Preferences (oral judgment)
9	Extreme
7	Very Strong
5	Strong
3	Moderate
1	Equal
2, 4, 6, 8	Intervals between strong preferences

criterion of repair and maintenance average rate in Ghaemshahr. According to this figure, tractor T1 with 0.162 proportion and tractor T10 with 0.017 had the maximum and minimum contribution, respectively, and according to Fig. 6, which shows the weight of options with regard to the criterion of repair and maintenance average rate in Ahvaz, tractor T1 with 0.144 and tractor T9 with 0.024 had the maximum and minimum contributions, respectively.

Fig. 7 shows the weight of options with regard to the criterion of average power in Ghaemshahr. According to this figure, tractor T10 with 0.203 and tractor T13 with 0.019 had the maximum and minimum preferences, respectively, and Fig. 8 shows the weight of option with regard to the criterion of average power in Ahvaz. According to this figure, tractor T10 with 0.156 and tractor T15 with 0.023 had the maximum and minimum preferences, respectively.

Fig. 9 shows the weight of options with regard to the criterion of price average in Ghaemshahr. According to this figure, tractor T11 with 0.218 and tractor T10 with 0.007 had the maximum and minimum preferences, respectively, and Fig. 10 shows the weight of options with regard to the criterion of average price in Ahvaz. According to this figure, tractor T11 with 0.218 and tractor T10 with 0.007 had the maximum and minimum preferences, respectively.

Fig. 11 shows the weight of options with regard to the criterion of ergonomic average in Ghaemshahr. According to this figure, tractor T10 with 0.198 and tractor T9 and T11 with 0.034 had the maximum and minimum preferences, respectively, and Fig. 12 shows the weight of option with regard to average ergonomic criterion in Ahvaz. According to this figure, tractor T8 with 0.151 and tractor T11 with 0.027 had the maximum and minimum preferences, respectively.

Fig. 13 shows the weight of options with regard to average model criterion in Ghaemshahr. According to this figure, tractor T7, T8, T9 with 0.094 and tractor T15 and T11 with 0.039 had the maximum and minimum preferences, respectively, and Fig. 14 shows the weight of options with regard to average model criterion in Ahvaz. According to this figure, tractor T7,

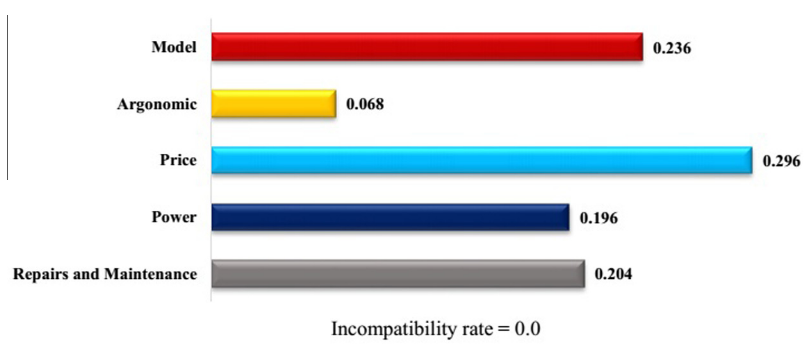

Fig. 3 – Paired comparison of criteria according to the purpose (Ghaemshahr).

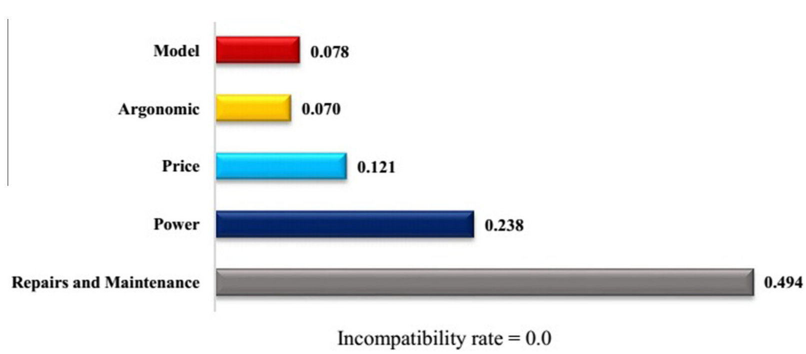

Fig. 4 – Paired comparison of criteria according to the purpose (Ahvaz).

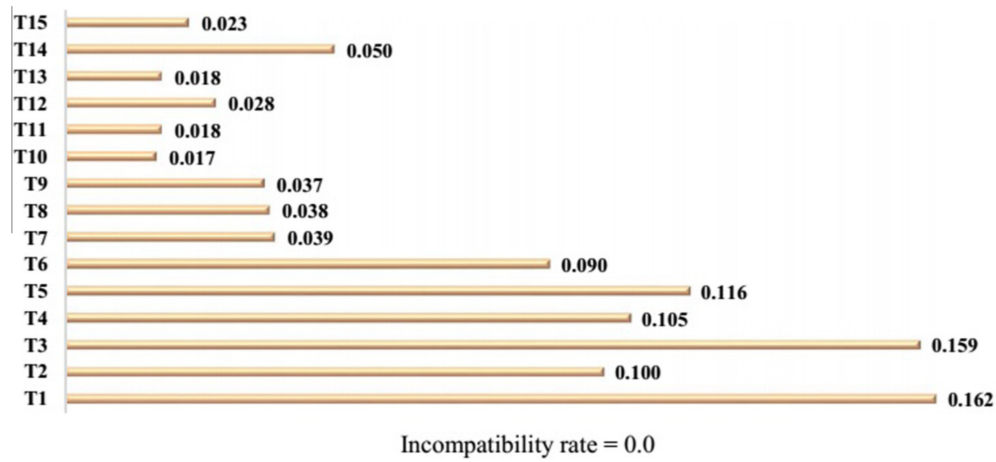

Fig. 5 – Paired comparison of options according to repair and maintenance mean criterion (Ghaemshahr).

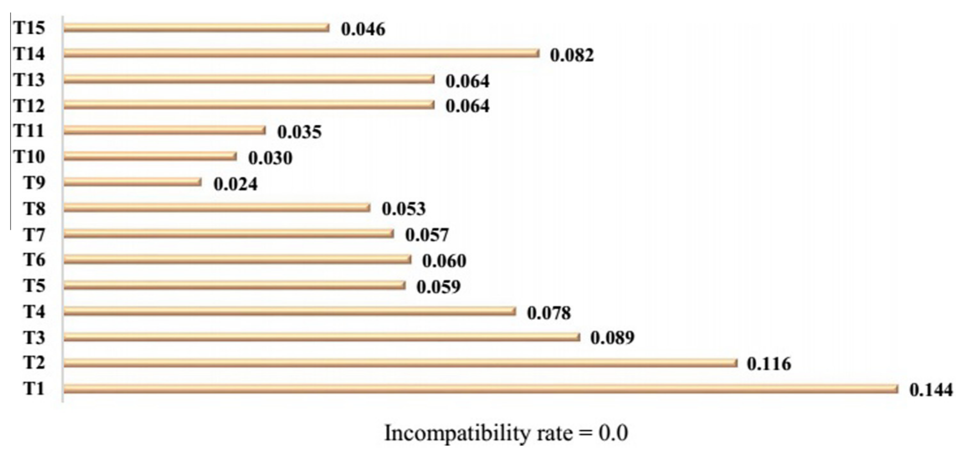

Fig. 6 – Paired comparison of options according to repair and maintenance mean criterion (Ahvaz).

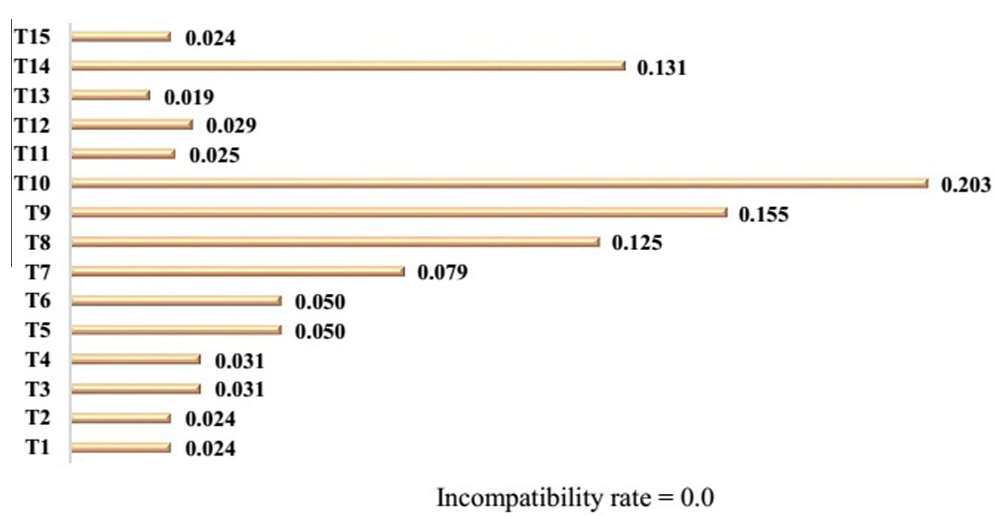

Fig. 7 – Paired comparison of options according to power mean criterion (Ghaemshahr).

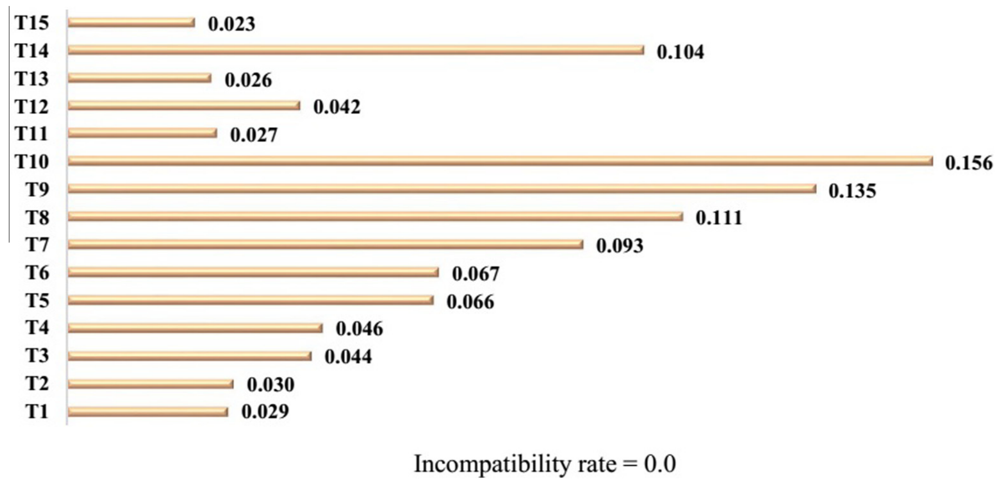

Fig. 8 – Paired comparison of options according to power mean criterion (Ahvaz).

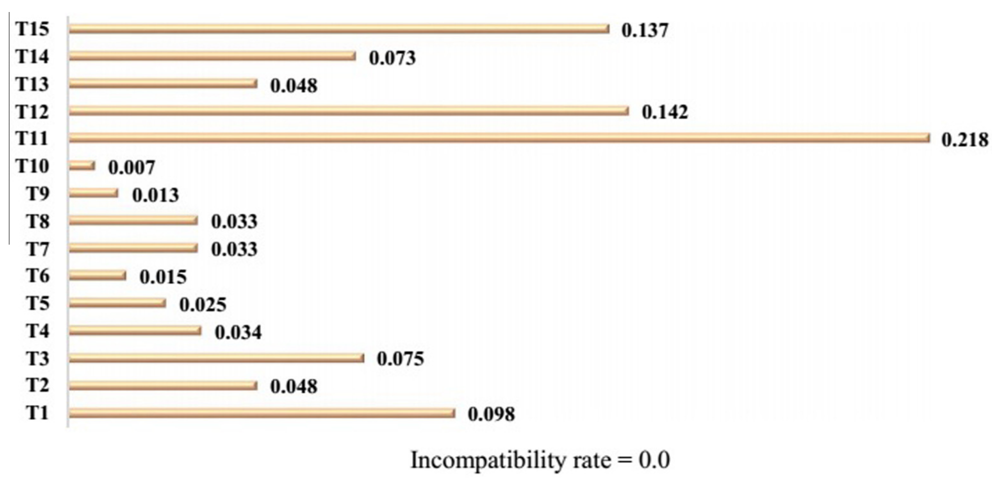

Fig. 9 – Paired comparison of options according to price mean criterion (Ghaemshahr).

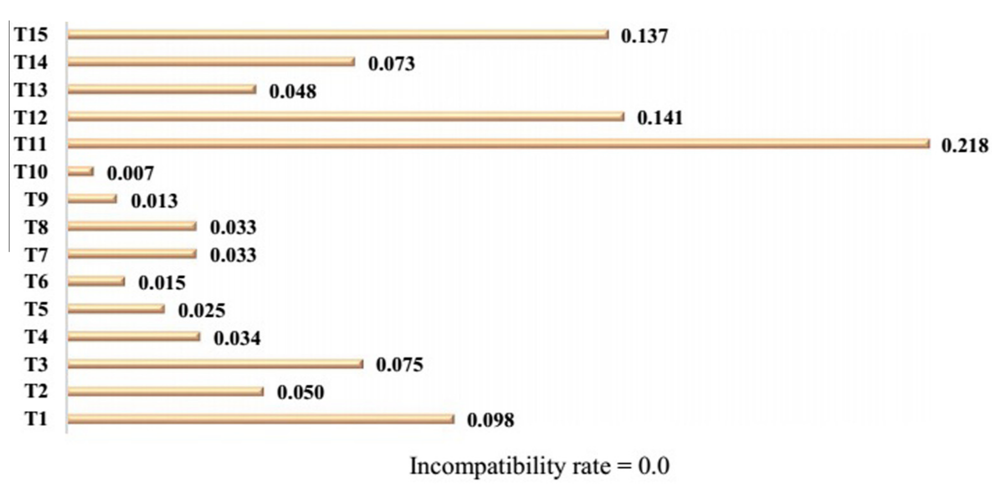

Fig. 10 – Paired comparison of options according to price mean criterion (Ahvaz).

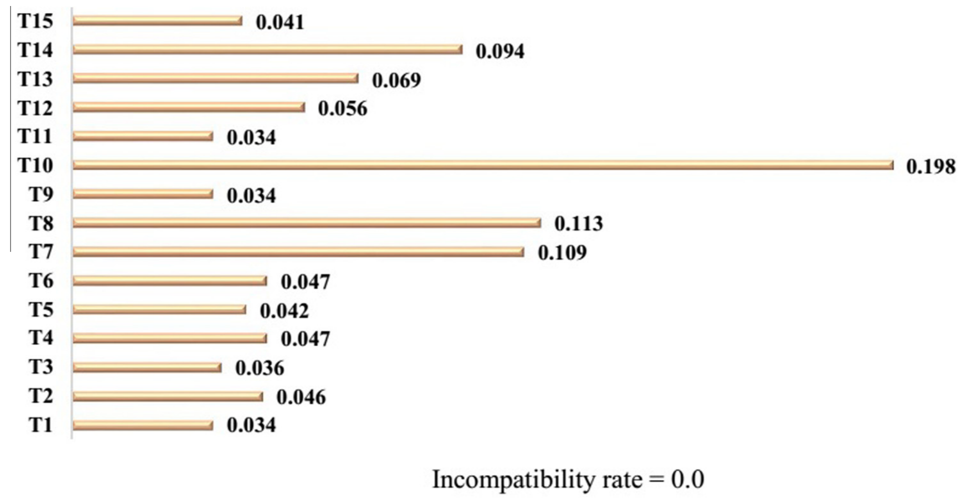

Fig. 11 – Paired comparison of options according to ergonomic mean criterion (Ghaemshahr).

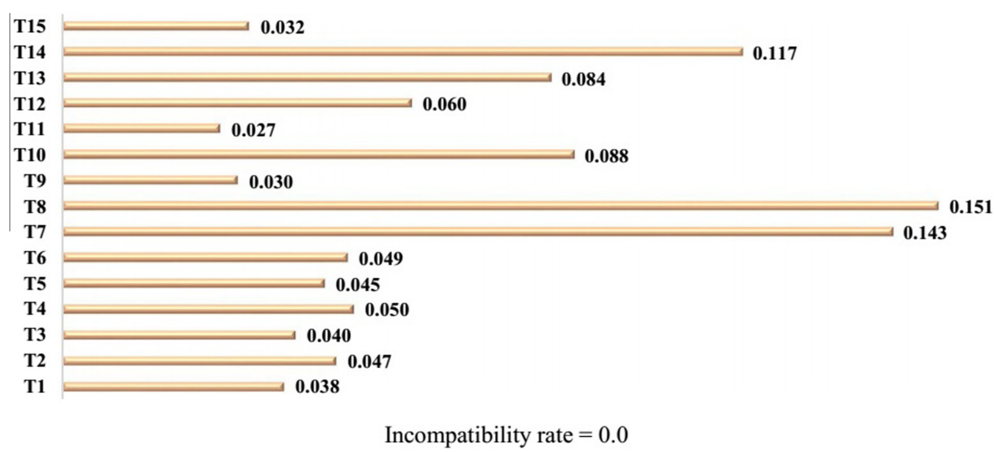

Fig. 12 – Paired comparison of options according to ergonomic mean criterion (Ahvaz).

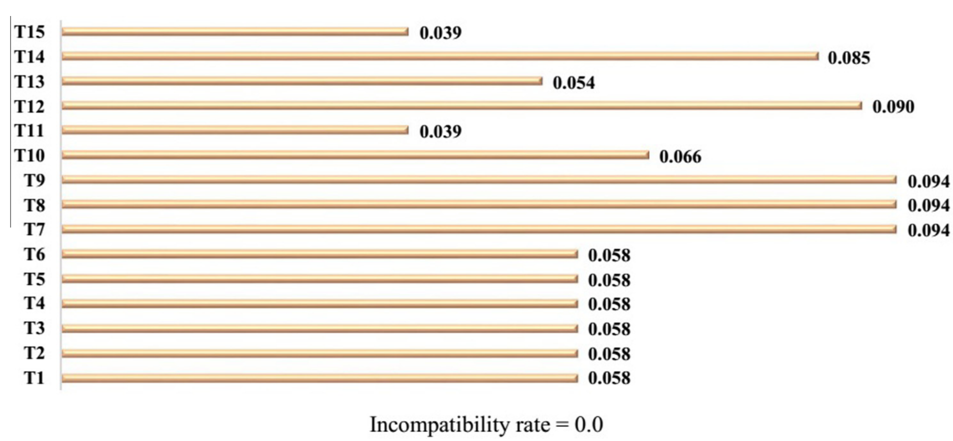

Fig. 13 – Paired comparison of options according to model mean criterion (Ghaemshahr).

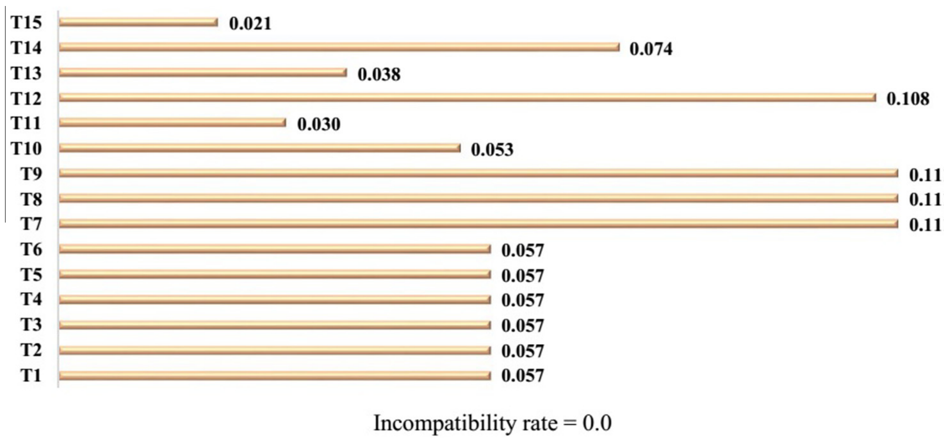

Fig. 14 – Paired comparison of options according to model mean criterion (Ahvaz).

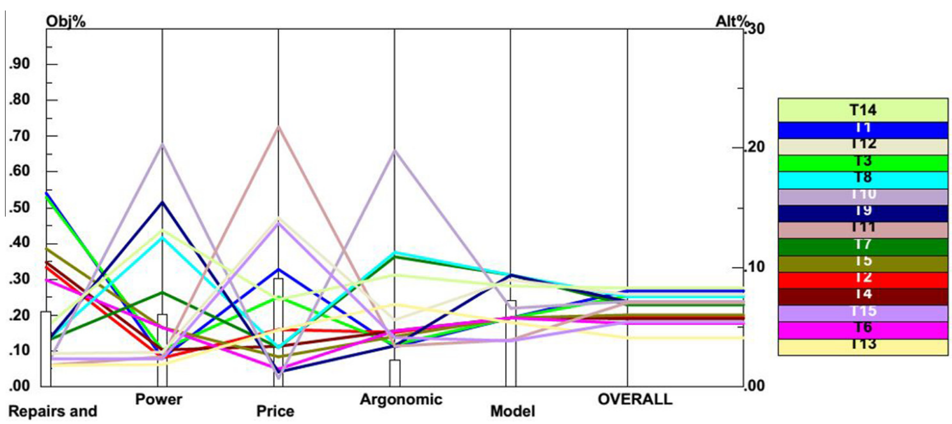

Fig. 15 – Synthesis of options and criteria according to purpose (Ghaemshahr).

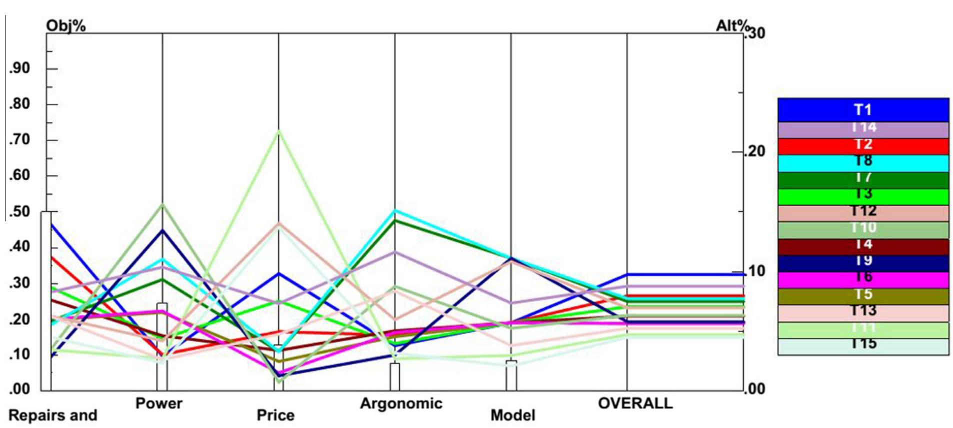

Fig. 16 – Synthesis of options and criteria according to purpose (Ahvaz).

T8 and T9 with 0.111 and tractor T15 with 0.021 had the maximum and minimum preferences, respectively.

3.3. *Synthesis*

Based on the results of synthesis of options and criteria with regard to the purpose of the study (Figs. 15 and 16), it could be concluded that among the existing and studied tractors in Ghaemshahr and Ahvaz, T1 and T12 with 0.083 were the most appropriate in Ahvaz and T14 with 0.083 was the most appropriate in Ghaemshahr. Incompatibility rate for all the comparisons is zero, so criteria are totally compatible with purpose and options (see Figs. 17 and 18).

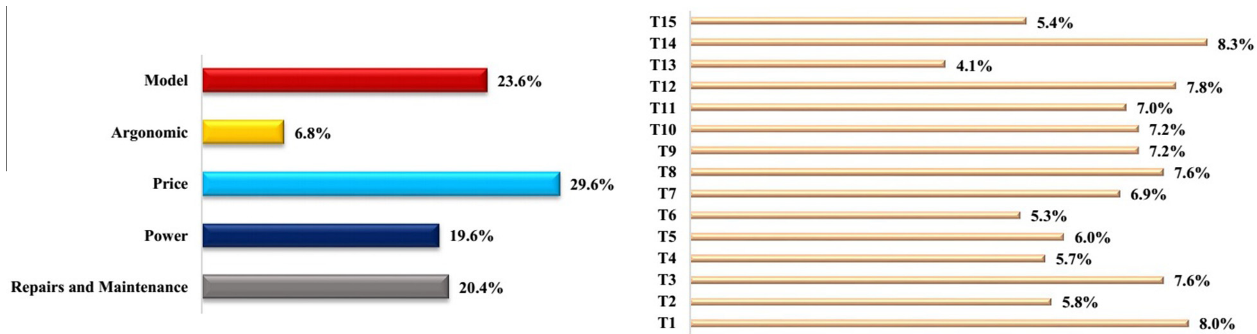

Fig. 17 – Percent of options and criteria according to purpose (Ghaemshahr).

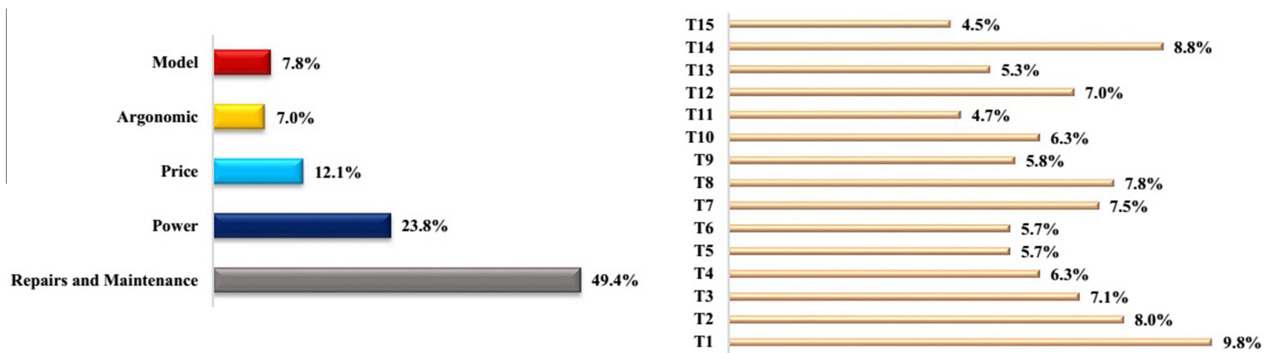

Fig. 18 – Percent of options and criteria according to purpose (Ahvaz).

4. Conclusions

The results were shown that the maximum effect on tractor selection with 49.4% was related to repair and maintenance and the minimum was related to ergonomic with 7% in Ahvaz, and the maximum effect was related to price with 29.6% and the minimum was affected by ergonomic with 6.8% in Ghaemshahr.

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